Renewable and Sustainable Energy Reviews 39 (2014) 1074–1088

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Current energy scenario and future prospect of renewable energy in Bangladesh

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ARTICLE INFO

Article history:
Received 12 August 2013
Received in revised form
7 July 2014
Accepted 19 July 2014
Available online 9 August 2014

Keywords:
Energy
Natural gas
Energy mix
Renewable energy
Bangladesh
Sustainability

ABSTRACT

Energy is the building block of modern civilization and a prerequisite for sustainable development. Global energy consumption will increase by 36% with an annual growth of 1.6% from year 2011 to 2030, comprising 88% fossil fuel share. Bangladesh is a developing country in the Southeast Asia, which is one of the lowest per capital energy consuming nation. The power crisis has become a major constraint to continued economic growth and energy sector of the country is currently facing serious challenge. Due to depleting nature and mono fuel dependent energy policy; finding alternative energy source has become imperative for the country. This study examined the current energy mix, present energy crisis and its way to overcome such scenario by utilizing alternative energy sources such as biomass, solar, wind and small scale hydropower energy, in the context of Bangladesh.

Among the renewable energy sources, biomass is found to be the most effective and utilizable. Potential electricity generation from biomass is 312.608 terawatt hour (TWh), where only 44.52 TWh is utilized. On the other hand, solar home system (SHS) has shown positive impact on socio-economic development in the rural areas by alleviating poverty and creating jobs. To assure national energy security, and aiming to provide constant and quality power supply to all citizens of Bangladesh, Government of People's Republic of Bangladesh (GOB) must strive to double its effort towards attaining greater renewable energy share by conversion, utilization and dissemination.

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http://dx.doi.org/10.1016/j.rser.2014.07.149
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1. Introduction

Energy is the building block of modern civilization and prerequisite for sustainable development. Global primary energy consumption is increasing with the pace of population growth and rapid urbanization. The primary energy sources include fossil fuels – oil, natural gas and coal. Until 2020, it is estimated that fossil fuels will dominate 90% of the total primary energy supply, if no breakthrough innovation would likely to occur [1]. In the last couple of decades, fossil fuel consumption increased dramatically. Primary energy consumption was 8146 million tonnes of oil equivalent (Mtoe) in 1991, and reached 12,274.6 Mtoe in 2011 (Fig. 1) [2].

Oil and other petroleum products are exhaustively used in transportation and other industrial operations. From 1991 to 2011, oil consumption increased by 28.56%. Coal and natural gas are also at the top of global consumption. It is projected that from year 2011 to 2030, global primary energy consumption will increase by 36% with an annual growth of 1.6%, in which fossil fuel will dominate 88% of the total energy supply [3]. However, fossil fuels in general, are depleting source of energy; and subsequently, building a society without considering alternative energy source will pose long term negative effect on sustainable development. At current production rate, proven oil and natural gas will last for 54.2 years and 63.6 years, respectively [2]. Explicit consumption of fossil fuels also gives rise to greenhouse gases (GHGs) concentration to the atmosphere. Among the GHGs; CO_2, NO_X and SO_2 emission are well-thought-out as an emerging issue to global community due to its persistent effect on environment and surrounding ecosystem, more importantly, on climate change. Due to rapid industrialization and abundant use of fossil fuel, CO_2 emission is increasing at constant pattern. Fig. 2 shows the global CO_2 emission from year 1981 to 2011 [2]. Global CO_2 emission was 19,074.5 million tons in 1981, which increased to 34,032.7 million tons in 2011 [2] and global CO_2 emission will rise by 85% from year 2000 to 2030 [4]. In amount, approximately, 40 billion tons of CO_2 will accumulate to the atmosphere by 2030 [5]. Renewable energy sources such as solar, biomass, wind and hydropower are now considered, as sustainable alternative mitigating climate change. At present, renewable energy accounts for 11% of the total energy supply, and by 2070, the share will be 60% [6].

Past few decades, transformation of agricultural economy to industrialization is seen throughout the developing countries. Almost all emerging economies in the developing world are having high gross domestic product (GDP) growth. Like others, energy supply largely depends on fossil fuels in Bangladesh. Power crisis has become a crucial issue for the past few years as power generation is largely dominated by indigenous natural gas, which is now showing depleting trajectory [7,8]. In 2012, total electricity generation was 35,118 million kilowatt hour (kWh) out of which 27,795 million kWh was generated from 151 billion cubic feet (BCF) of natural gas [9]. Moreover, in recent years, quick rental power plants have been established to minimize immediate power shortage, which also raised the price of electricity. At peak season during summer, the country experiences severe power crisis with an average 1500 megawatt (MW) net deficit [10]. More than 80% of the population resides at rural areas, and only 20% has interrupted access to grid connected electricity [11,12]. In this duel folded power crisis scenario, renewable energy could provide viable alternative mitigating present shortage and ensuring long range energy planning. Western-world has already identified such potential, and started diverting energy mix by harnessing alternative energy resources. For instance, in Turkey, greenhouse heating for agricultural production can be done extensively with the help of biogas, solar, and ground source heat pump hybrid system [13–15]. Countries those

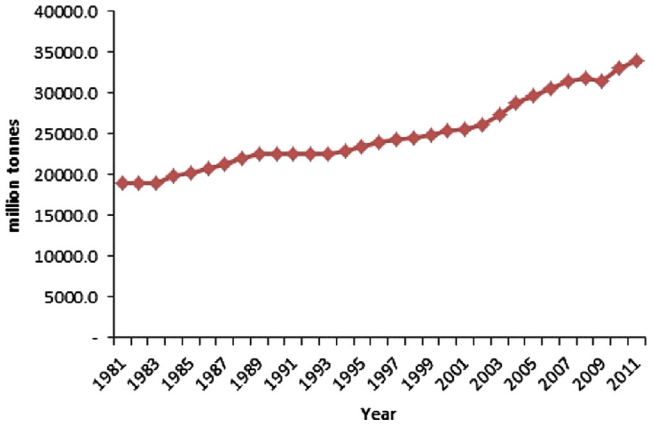

Fig. 2. Global carbon dioxide emission [2].

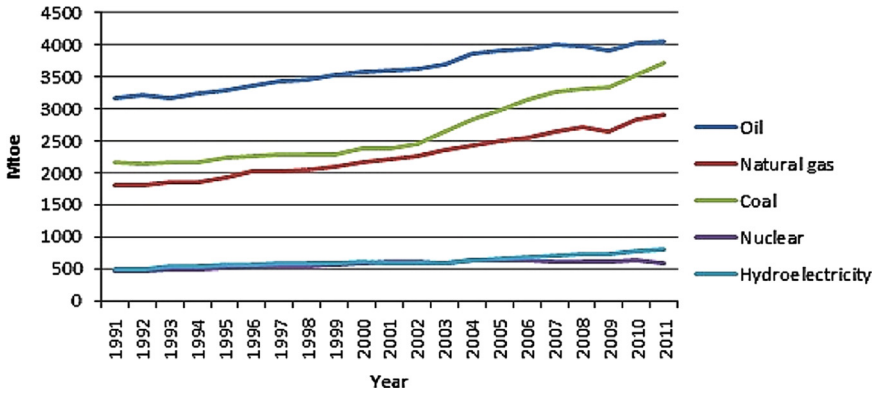

Fig. 1. Global primary energy consumption [2].

Nomenclature

BCF	billion cubic feet
BPRE	Bangladesh Policy of Renewable Energy
BDT	Bangladesh Taka
BRAC	Bangladesh Rural Advancement Committee
BCAS	Bangladesh Center for Advance Studies
BMD	Bangladesh Meteorological Department
BPDB	Bangladesh Power Development Board
BWDB	Bangladesh Water Development Board
BTS	Base Transceiver Station
CNG	compressed natural gas
CSP	concentrating solar power
CHT	Chittagong Hill Track
CO_2	carbon dioxide
DNI	direct normal insolation
GOB	Government of People's Republic of Bangladesh
GDP	gross domestic product
GS	Grameen Shakti
GP	Grameen Phone
IDCOL	Infrastructure Development Company Limited
LGED	Local Government Engineering Department
LFR	Linear Fresnel Reflector
NGOs	non-government organizations
NO_X	mono-nitrogen oxides
PV	photovoltaic
PREGA	promotion of renewable energy, energy efficiency and greenhouse gas abatement
PSMP	power system master plan
RSF	research support facility
RM	Malaysian Ringgit
SO_2	sulfur dioxide
SHS	solar home system
SRE	sustainable rural energy
TCF	trillion cubic feet
USEPA	United States Environmental Protection Agency

Subscript

EJ	exajoule
Mtoe	million tonnes oil equivalent
MWh	megawatt hour
kWh/m^2	kilowatt hour per meter square per year
kcal/kg	kilo calorie per kilogram
km^2	kilometer square
MW	megawatt
MT	metric tonne
GW	giga watt
TWh	terawatt hours
GWh	giga watt hours
MWp	megawatt peak
TWh/yr	terawatt per year
kW/m^2	kilowatt per meter square
m	meter
m/s	meter per second
km	kilometer
kW	kilowatt
Wp	watt power

possesses geothermal energy can utilize ground source heat pipes and heat exchanger in de-icing process of pavements and bridge slabs [16–18]. However, in most cases, energy storage is an imperative part to utilize solar energy [14]. At present, renewable energy shares 16.7% of the global final energy consumption (Fig. 3). In recent times global investment on renewable energy has increased over 17% [19]. In 2011, US$257 billion was invested. World's top oil importer – China, invested $51 billion on renewable technologies in 2011, which was higher than Germany, United States, India and Italy [20]. Developing countries are also showing similar pattern of development in the energy sector [21]. Like other developing countries, Bangladesh is also blessed with ample renewable energy sources such as biomass, solar, wind and small hydropower. Thus, it is imperative to utilize renewable energy sources as an alternative to depleting energy sources which could lead to sustainable solution to present energy crisis and future national energy security. Moreover, effective and efficient use of renewable energy can mitigate CO_2 emission from conventional fuel energy mix in grid connection [22]. Therefore, this study attempts to address current energy scenario of Bangladesh and illustrates a comprehensive review on explored renewable energy sources for its effective utilization both in urban and rural areas of Bangladesh.

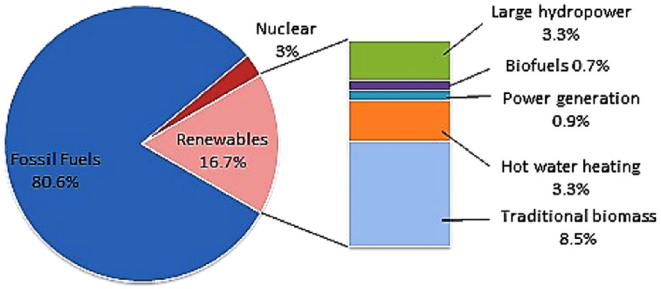

Fig. 3. Renewable energy share of global final energy consumption [13].

Fig. 4. Geographical map of Bangladesh.

2. Geographical location and economy of Bangladesh

The People's Republic of Bangladesh is a country in the north eastern part of south-Asia-located between 23°34′N and 26°38′N latitudes and 88°01′E and 92°41′E longitudes. There are six divisions, namely Dhaka, Rajshahi, Barisal, Chittagong, Sylhet and Khulna (Fig. 4). Total land area of the country is 147,570 km^2. As of 2012, the population of Bangladesh reached over 154 million (i.e., 1048 people/km^2) with growth rate of 1.2% per year, resembling it, one of the most densely populated country in the world [23]. Climatic condition of the country is generally divided in 4 distinct seasons. From December to February, the weather is cold. Summer generally starts in March and ends in May. Monsoon exists during June to September, and autumn – from October to December. The average temperature during winter and summer is 20 °C and 27.75 °C, respectively [6].

The economy of the country largely depended on agriculture and forestry. More than 80% of the population resides in the rural areas, where agriculture is the major occupation among the villagers. Other notable sectors that contribute to the economy are fishing, mining, manufacturing, power sector, retail trade, and large service sectors. For the past 5 years, GDP is continued to rise – estimated over 6%, annually. In 2011, it was 7% [23].

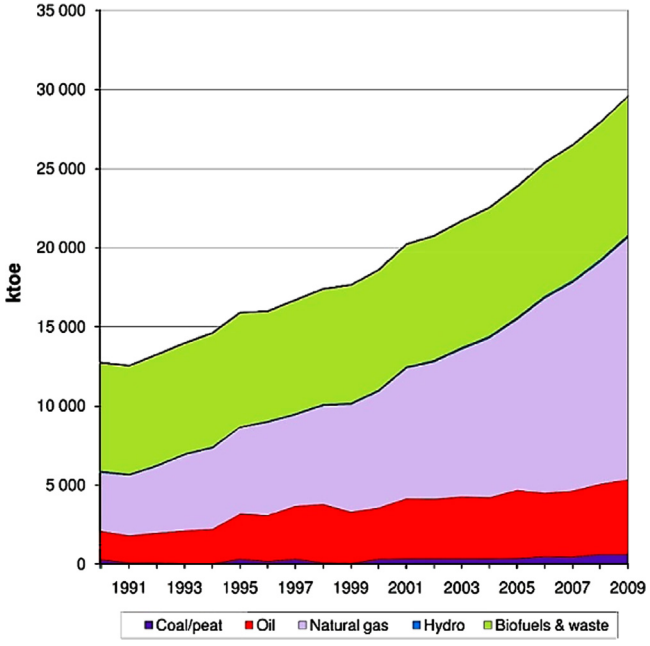

Fig. 5. Total primary energy supply in Bangladesh [26].

2.1. Current energy scenario

Rapid growth of population, urbanization and industrialization triggered energy consumption phenomenally in the country. Primary energy consumption was 12.7 Mtoe in 2000 and reached 24.3 Mtoe in 2011 [2]. Expected power demand will rise by 185% by year 2020 [24]. Per capita electricity consumption is 212 kWh, which is one of the lowest compared to other developing country like India (480.5 kWh) and Pakistan (456.2 kWh) [25]. Per capita energy consumption is a measure of development, and recent research revealed that per capita energy consumption and GDP growth has reciprocal relationship [10].

Although primary energy supply has been increased steadily for past 20 years, there is no substantial alternative energy sources have been developed that could provide sustainable solution to bulk energy deficit. Within next few decades, it is expected that Bangladesh will face serious energy crisis. Energy demand is skyrocketing which is currently being supplied by depleting fossil fuel energy sources such as natural gas, coal, oil and petroleum products (Fig. 5) [26]. Biomass share in the total primary energy supply is considerable. 65% of the population of the country resides at rural areas and 44% are living under the poverty line for whom biomass energy is being used as primary energy source [27]. Biomass shares 46% of total energy supply [6].

From 1992 to 2011, final energy consumption has increased over 200%. However, per capita primary energy consumption was 0.152 Mtoe in 2011. But total primary energy consumption increased by 2.59% annually from year 1980 to 2010 [2]. Fig. 6 shows the final energy consumption from 1990 to 2011.

Among the indigenous primary energy sources in Bangladesh, natural gas is widely used in power plants, fertilizer factories, industrial entities, and most recently in transport sector as compressed natural gas (CNG). As a primary energy source, natural gas accounts for 73% of the total energy consumption [28]. Currently, natural gas accounts for 67.11% of total electricity generation. Imported furnace oil, coal, diesel and hydropower also contribute to electricity generation of 1804 MW (21.70%), 511 MW (6.15%), 200 MW (2.41%) and 220 MW(2.65%), respectively as of June 2012 [9]. However, Bangladesh will face serious energy supply shortage in near future as per current estimation. At annual GDP growth of 7%, it is estimated that, by 2021, electricity demand will rise up to 18,838 MW, and by 2030, it will be 33,708 MW [29]. By 2021, GOB envisioned providing uninterrupted electricity supply to all citizens as per mentioned in the power system master plan (PSMP) 2010. Total generation capacity will be 20,000 MW with a per capita consumption of 600 kWh, by 2021. By then, natural gas will account for 3115 MW of electricity generation, which reflects mono fuel dependency. In an overall energy demand scenario by all sectors, 5.6 BCF of natural gas will be required by 2025. On the

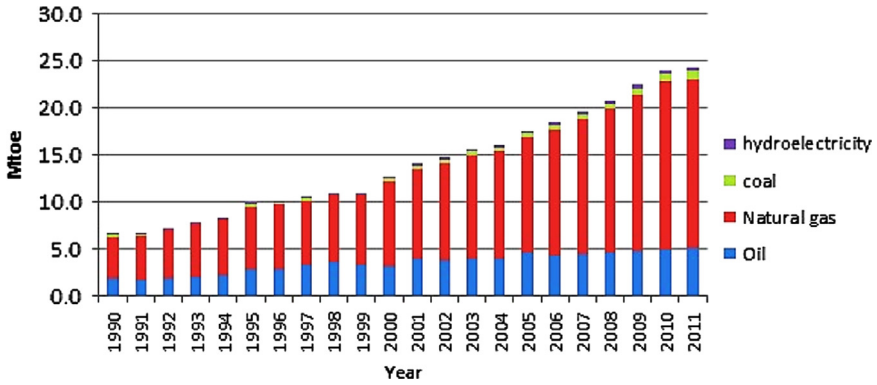

Fig. 6. Final energy consumption in Bangladesh (by fuel type) [2].

other hand, present reserve of natural gas is 11.77 trillion cubic feet (TCF) which is supposed to be diminished by 2019 [30].

Thus, it has become an imperative issue to divert fossil fuel energy mix to alternative energy sources achieving long term energy security. From that aspect, renewable energy should be considered as the most viable solution to meet present as well as future energy demand towards attaining sustainable development.

3. Energy mix in Bangladesh

3.1. Natural gas

Natural gas is the most valuable indigenous natural resources of Bangladesh, and playing a pivotal role in the growth of the economy. It shares 75% of the primary commercial energy supply and 79.15% of power generation [9]. Until 2012, 24 gas fields have been discovered with proven reserve of 37.680 TCF, out of which 26.877 TCF is recoverable. Currently, 20 gas fields are in full operation, and as of June 2012, total 10.514 TCF of natural gas has been produced [9]. Fig. 7 shows the production and reserve of natural gas in Bangladesh [9].

Among different sectors, power plants have the largest share of natural gas consumption, which is 41%, followed by industry – 17%, captive power sector – 16%, domestic sector – 12% and fertilizer factories – 8% [31]. In 1992, natural gas demand in power sector was 88.1 BCF that reached 304.3 BCF in 2012, which is a net 200% increase. In fiscal year 2010–2011, approximately 38.54 BCF was consumed by CNG sector, which is 6% of the total natural gas consumption, and it is expected to increase 120.9 BCF by 2015. From 1991 to 2012, demand for natural gas increased by 300% (Fig. 8). It is estimated that from now on demand for natural gas will increase by 73.78% until 2014–2015.

Mono fuel dependency on natural gas is seen in all over the industry which might pose threat to future long range energy sector planning and sustainable development of the country. Effective fuel diversification is an essential part of long term planning. Economic

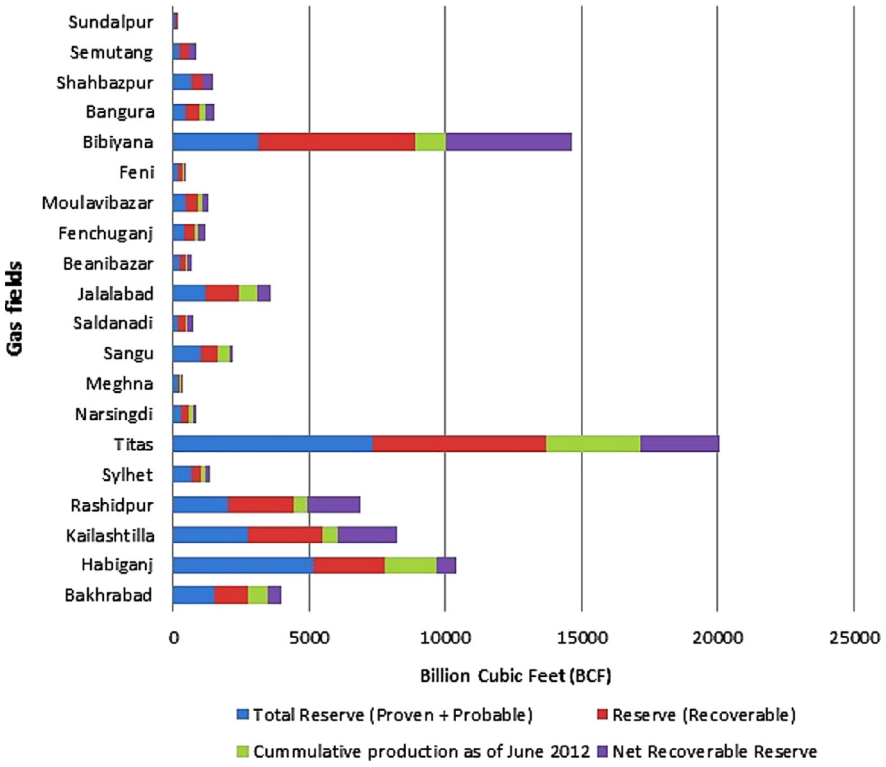

Fig. 7. Production and reserve of gas fields in Bangladesh [9].

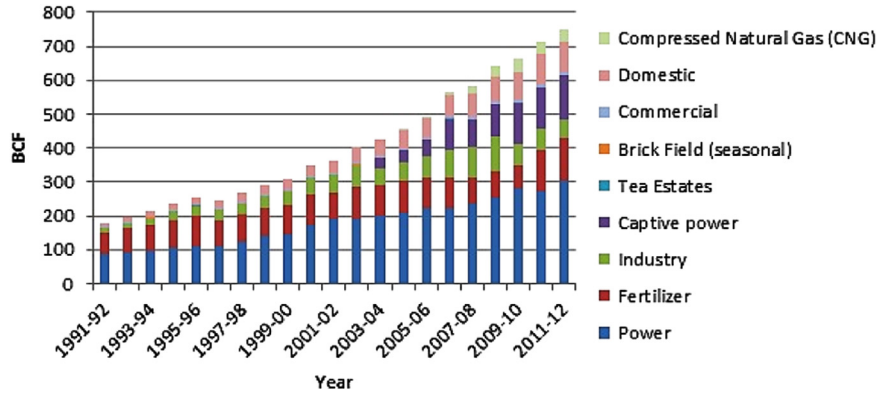

Fig. 8. Consumption of natural gas by sectors [9].

growth of the country requires steady and cost effective application of available energy sources without scarifying environmental degradation. Extensive dependency on natural gas should be reduced considering its future demand and declining reserve. Finding out alternative energy sources to minimize over dependency on natural gas and other primary energy sources, present energy mix should be redefined based on purchasing power parity, economic growth and availability of resources.

3.2. Oil

Bangladesh has no significant oil reserve except the Haripur oil reserve which was discovered in 1989 at northwest of Sylhet district [32]. Estimated reserve is 1.4 Mtoe, out of which 0.84 Mtoe was supposed to be recovered as of year 2004 but the exploitation was abandoned due to poor oil quality and presence of water in the oil zone [6]. Bangladesh heavily depends on imported crude and refined petroleum products for transportation, industrial heating and small scale power generation. At present, demand for refined oil in the country is 4.87 million metric tonne (MT) at an annual growth rate of 5%. Import of crude oil and refined petroleum products from financial year 1998–1999 to 2011–2012 is shown in Fig. 9 [9].

A large amount of revenue budget is spent every year for purchasing imported petroleum. However, GOB lately started implementing rental and quick rental power plants on an ad hoc basis for electricity generation. Imported diesel and furnace oil is required for running such expensive power plants, and in 2011, GOB subsidized US $0.56 billion for the power plants which resulted in higher electricity price and greater economic burden [10]. Developing countries like Bangladesh require affordable energy and electricity supply which must be meet with available energy sources, rather imported energy sources. Economic viability and environmental concerns should be addressed with present energy demand, and in such circumstances, finding out alternative energy sources and its utilization has to be ensured.

3.3. Coal

Coal is the most abundant and economical energy sources not only in Bangladesh but also, all over the world [33]. At present, coal as primary commercial energy accounts for 39.8% of the world's electricity generation [34]. In the USA and China, coal is widely used in power generation [35]. In Bangladesh, coal shares 3.25% of the actual generation of electricity. National coal policy is under process, and it is expected that realistic planning and allocation of national budget could provide meaningful development in the sector which was previously, long halted due to administrative and technological barrier [34]. So far, five coal deposits have been discovered at the north-west part of Bangladesh. Current estimated reserve is approximately 3300 million MT which is equivalent to 45–50 TCF of natural gas [9]. Most of the coal deposits contain bituminous type of coal and that has high calorific value. Among the deposits (Table 1) [6,9,34], Barapukuria has a daily production capacity of approximately 2500–3000 MT, and as of June 2012, total 4.55 million MT of coal has been produced. Thermal power plant located at Barapukuria with an installed capacity of 250 MW, requires 2000 MT of coal per day [6].

Among various types of coal, bituminous is comparatively contains higher calorific value and carbon content. High carbon content and higher heating value determine the suitability of coal for electricity generation [34]. Table 2 shows different type of coal, and their energy value. Generally bituminous type of coal is used for electricity generation. At present, 39.8% of the world's electricity is generated from coal. Coal deposits found in Bangladesh consist of bituminous type of coal, and among the deposits, Barapukuria coal has the calorific value ranges from 5546 to 7202 kilo calorie per kilogram (kcal/kg) [36], which is considerably optimum for electricity generation. National coal policy has to be implemented to have net gain from the coal reserve. On the other hand, GOB planned to import coal from India for electricity generation, leaving the national coal reserve untapped. This reflects an ill-fated coal policy which needed to be reviewed. Extensive

Table 1
Coal deposits in Bangladesh [6,9,25].

Name of coal deposits	Year of discovery	Depth of coal layer (m)	Area (km^2)	Reserve (million MT)	Type of coal
Khalaspir, Rangpur	1989	257–451	5.75	400	Bituminous
Barapukuria, Dinajpur	1985	118–506	6.68	390	Bituminous
Phulbari, Dinajpur	1997	> 150	24	572	Bituminous
Dighipara, Dinajpur	1995	250	15	600	Bituminous
Jamalgonj, Jaipurhat	1962	640–1158	11.7	1053	Bituminous

Table 2
Coal ranks and properties [28,29].

Type of coal	Calorific value (kcal/kg)	Volatile matter content (%)	Carbon content (%)	Rank
Lignite	< 4165	> 31	55–61.5	Lowest
Subbituminous	4165–5700	> 31	61.5–64	Low-middle
Bituminous	> 5700	> 10	64–86	High-middle
Anthracite	> 5700	< 10	> 86	Highest

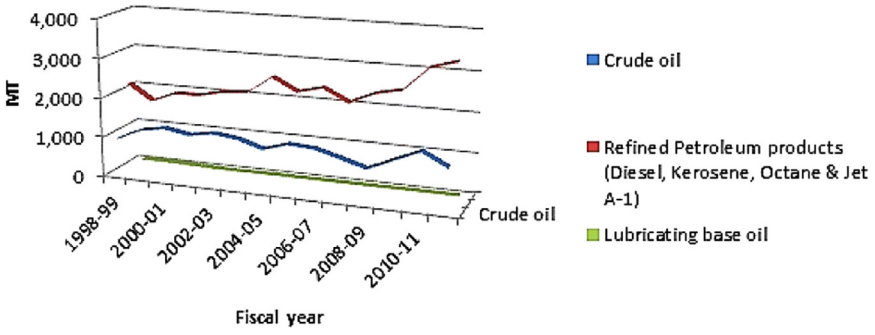

Fig. 9. Trend of petroleum import in Bangladesh [9].

Table 3
Prospects of hydropower in selected Himalayan countries (in MW) [32].

Country	Installed capacity	Generation capacity	Hydropower potential
Bangladesh	4120	218	755
Bhutan	481	469	23,670–30,000
India	124,287	32,300	84,000–150,000
Nepal	684	627	43,000 – 83,000

utilization of coal could endanger harmonized balance of ecosystem and possibility to emit further CO_2.

3.4. Hydropower

Hydropower is the most promising energy sources as this source is regenerative and eco-friendly. Hydropower accounts for approximately 20% of the world's electricity generation which is around 675,000 MW. By 2020, global annual electricity generation from hydropower will reach 4096 TWh [39]. Unlike Himalayan countries, due to flat terrain, Bangladesh has limited hydropower potential [40]. Hydropower electricity generation largely depends on available head and generation capacity. Table 3 shows the hydropower potential in different Himalayan countries [41]. Hydro power contribution for electricity generation is less than 4%, in Bangladesh. The only large scale hydropower plant is located at Karnafuli River, Kaptai in Chittagong district. The generation capacity of the power plant is 218 MW. The construction area of the plant is11×10^3 km^2 with a basin capacity 6.5×10^9 m^3. As of July 2013, the plant shared 3.95% of total electricity generation of the country [42].

4. Renewable energy in Bangladesh

Renewable energy sources are defined as those that are abundant in nature and derived from natural process with no depletion in the course of utilization. Bangladesh is blessed with renewable energy sources such as biomass, wind, solar and small scale hydropower energy [43]. Among the renewables, solar and biomass found promising and effective in the context of Bangladesh [11]. Due to flat terrain and low water head, small scale hydropower found little interest; however, potential of small hydropower energy source is found 500 MW [44]. Utilization of wind energy is limited due to insufficient ground data [45]. At present, renewable energy shares only 0.5% of total energy mix (Fig. 10) [20]. Bangladesh is still at nascent stage to utilize renewable energy at commercial scale [43]. However, according to Bangladesh Policy of Renewable Energy (BPRE) 2008, target dissimilation of renewable energy has set to 5% by 2015 and 10% by 2020 [46]. Available technology and total energy production from renewable energy sources are summarized in Table 4.

4.1. Biomass energy

Biomass is extensively used as alternative energy sources in developing countries for the purpose of cooking, heating and other necessary household activities. Generally biomass refers to rice husk, crop residue, jute stick, wood, animal waste, municipal waste etc. It is the fourth largest source of energy. At present, biomass accounts for 8.5% of the global final energy consumption [20]. It can contribute to the overall environment quality by reducing emission, and as a promising source of electricity generation. Global biomass energy share will be 50% by 2050, in terms of consumption [48]. Like other developing countries in Asian region, biomass accounts for 48% of the total energy consumption

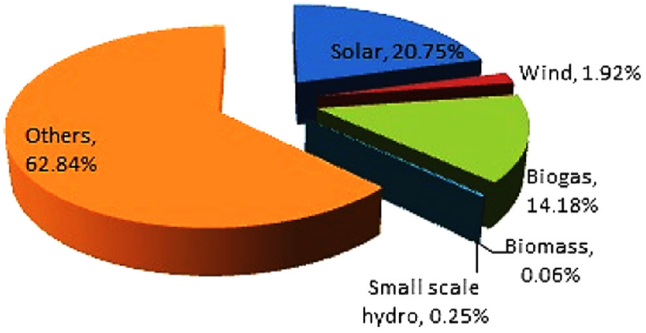

Fig. 10. Renewable energy share in Bangladesh [20].

Table 4
Selected renewable energy technology and energy production in Bangladesh [37].

Year	Electricity/ energy production by technology	Energy production	Sector wise installed capacity	Total installed capacity	Electricity production, total share (%)
2007	Non-technology specific	–	0.238 GW	**0.238 GW**	–
2008	Wind	2.0 GWh	–	**0.241 GW**	**4.3**
	Solar PV	28.0 GWh	–		
	Hydropower	1.5 TWh	–		
	Sub total	**1.5 TWh**	–		
2009	Wind	2.0 GWh	–	**0.246 GW**	**4.2**
	Solar PV	37 GWh	–		
	Hydropower	1.6 TWh	–		
	Biogas	–	1 MW		
	Sub total	**1.6 TWh**			
2010	Wind	2.0 GWh	–	**0.3 GW**	**3.9**
	Solar PV	55.0 GWh	–		
	Hydropower	1.6 TWh	–		
	Sub total	**1.6 TWh**			
2011	Wind	2.0 GWh	1.0 MWp	–	**4.6**
	Solar PV	78.0 GWh	68.3 MWp		
	Solar heating/ cooling	–	870,000 nos.		
	Hydropower	1.9 TWh	230 MW		
	Sub total	**2.0 TWh**			
2012	Solar PV	–	3.0 MW	–	–
	Solid biomass	–	37.0 MW		
	Hydropower	–	230 MW		

in Bangladesh [49]. In Bangladesh, traditional biomass as energy supply source such agricultural residues, wood wastes and animal dung, represents 46%, 34% and 20%, respectively [50–52]. From environmental and economic sustainability view point, biomass energy is an effective energy source for rural population of the country. Bangladesh is endowed with rich biomass energy with a potential electricity generation capacity of 160.93 TWh from agricultural crop residues, followed by 121.768 TWh from recoverable waste, and 29.91 TWh from fuel wood, saw dust and tree residues [6]. Table 5 shows available technology used to tap the potential of biomass energy in Bangladesh. Lately, Infrastructure Development Company Limited (IDCOL) financed 238.65 million Bangladesh Taka (BDT) in biomass based technologies including biomass power plant, biomass gasification plant and biogas based electricity generation plant [53].

4.1.1. Biogas

Biogas is a very promising renewable energy resource derived from various residues, mainly from animal and municipal wastes.

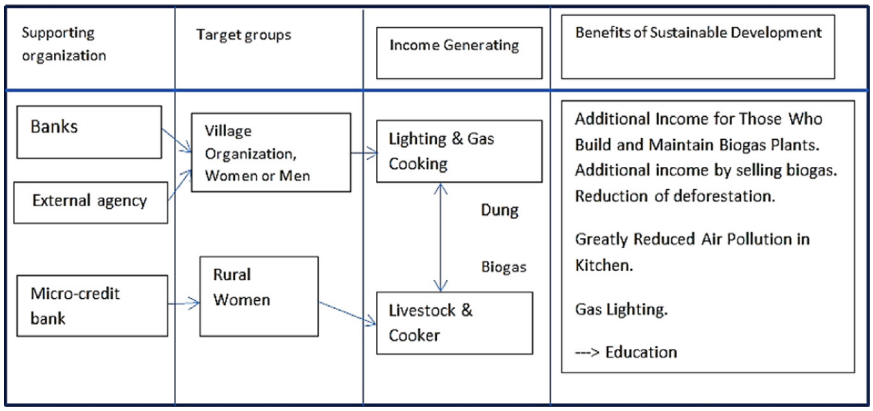

Fig. 11. Simplified model of biogas dissemination in rural Bangladesh (adopted from [55,57]).

It can be used for cooking and power generation purposes [55]. Technology dissemination in this particular renewable energy source is very poor all over the country [43,51,50]. As of April 2012, IDCOL installed 22,549 biogas plants all over the country [56]. IDCOL also financed a 250 kW biomass based power plant at Kapasia, Gazipur, in which local agricultural residues such as rice husk is used [55]. Municipal solid waste could also be an important source of biogas production [51], which is found very limited application. Fig. 11 shows a simplified model of biogas dissemination in rural Bangladesh. However, previous research conducted by the authors in [43] found that as of July 2009, 32% of the total installed biogas plants are not working due to lack of appropriate maintenance and technical knowledge. Constant monitoring and evaluation process should be carried out in the projects sites for project's future sustainability.

4.1.2. Bio-fuel

Biomass utilization is categorized by bio-product, bio-energy and bio-power [58]. So far, Bangladesh is in early stage developing bio-fuel from biomass energy. Biofuel is produced from trans-esterification of oil derived from various energy crops [59]. Table 6 shows average biodiesel production from energy crops. Both developed and developing countries are putting effort to commercialize biofuels at large scale. For instance, government of Malaysia, lately introduced fuel diversification policy where it was emphasized on use of biodiesel as biofuel both in transportation and industrial operations [60]. In the end of 2009, Malaysian biodiesel blend B5 was introduced in the market, to reduce the dependency on imported diesel, and minimizing environmental pollution. B5 is the diesel blend that contains 5% palm oil derived methyl ester and 95% conventional diesel [61]. It is expected, when biodiesel is available all over the country; B5 biodiesel blend will replace 0.5 MT of conventional diesel that will save Malaysian Ringgit (RM) 1 billion, each month [62]. Transportation sector will continue its shares in consumption of petroleum and other liquid fuels, around 63%, estimated from year 2010 to 2040 [63]. Consumption of this large amount of fossil fuel will account for escalating GHG emission in future. As of year 2012, transportation and electricity production sector were accounted for 28% and 32% greenhouse gas emission, respectively in the United States [64]. Using biofuels as an alternative in the conventional fuel mix will reduce cost of transportation as well as CO_2 emission.

In Bangladesh, there is currently, no energy crops being produced for biofuels at commercial scale; however, on experimental basis, NITOL Motors, Bangladesh (the sole distributor of TATA Motors, India) has started working with two Singaporean firms to produce bio-fuel from ethanol molasses [50]. At initial stage the project will manufacture 12,000 l of bio-fuel, in which feedstock from sugar mills at the northern part of Bangladesh will be utilized [50]. The bio-fuel will be used as gasohol in the transportation vehicle, and the price will be reduced by 20–30% compared to other transport fuel [8].

Bangladesh can also utilize *Jatropha curcas* as energy crop which is a non-edible plant containing 50–60% vegetable oil. It is comparatively cheap feedstock for biodiesel production, generally grows on degraded soils with less fertility and moisture [65]. Recent study shows that *J. curcas* showed promising qualities as biodiesel in the climatic condition of Bangladesh. From a test operation, it was found that Jatropha showed relatively less emission of CO_2 around 1.33% where conventional diesel showed 9% in a diesel engine tested setup [66]. As a developing country, Bangladesh imports large amount of petroleum products with high price from international market. On the other hand, if Jatropha could be used instead of conventional diesel in commercial basis then, Bangladesh could save millions of foreign exchange. Environmental pollution from transportation sector would also be reduced utilizing such bio-fuel. Public policy regarding fuel regulation and necessary infrastructural should be developed for large scale Jatropha based biodiesel production [67].

Table 5
Biomass energy potential and achievement in Bangladesh [36,41].

Technology	Potential	Target capacity	Achievement
Domestic biogas system	8.6 million m^3	1,00,000 nos. (electricity generation capacity of 40 MW)	Ongoing project
Biomass gasification power plant	300 MW	3 MW	<1 MW
Biogas power plants	350 MW	6 MW	1 MW

Table 6
Average biodiesel production from energy crops [68].

Plant	lb. oil/acre	Gallons of biodiesel/acre
Algae	6757	700
Coconut	2070	285
Jatropha	1460	201
Rapeseed	915	126
Penut	715	112
Sunflower	720	99
Soybean	415	62

4.2. Solar energy

All over the world, solar energy is now considered as one of most promising renewable energy source. It has the highest potential to gain energy compared to other renewables. Approximate annual solar radiation on the earth surface is about 3,400,000 exajoule (EJ). Theoretically, available solar energy insolation could generate 1700 TW of electric power, and it is estimated that 1% of this energy can resolve world's present power demand [69]. It is also estimated that solar energy could deliver 450 EJ energy, equivalent to 7500 times higher of the world's energy consumption if the full potential is utilized [70]. Generally, solar energy is being utilized in lighting, heating, and most importantly; in power generation.

Technology that is widely used to harness solar energy potential is commonly known as photovoltaic (PV). The construction of solar PV consists of array of solar cells that convert solar light energy to electricity. Solar PV lately received considerable attention to global renewable energy products manufacturers as well as oil companies those are investing heavily on renewable energy technologies [3]. Both developed and developing countries identified the potential utilization of solar energy through solar PV. Global installed capacity of solar PV increased from 453 MW to 5.95 gigawatt (GW) in between year 1996 and 2008 [71]. However, most of the technological development in solar energy sector placed in the developed countries. For instance, in 1996, Germany had solar PV installed capacity of 11 MW which reached 248,200 MW in 2011. Table 7 shows solar PV installed capacity in selected Asian economies. Among them India and China are investing aggressively in solar PV sector [2]. Total installed capacity has been increased by 275% in China and 165.2% in India, from year 2010 to 2011 [2].

Geographical location of Bangladesh is considered to be an ideal place for solar energy utilization [45]. Annual solar radiation available is over 1900 kWh/m^2 [72]. Average solar irradiations varies from 4 to 6.5 kWh/m^2 [11]. However, significant variation in data of solar energy is evident, as there is no ground data currently available. Theoretically, Bangladesh receives approximately 69,751 TWh/yr equivalent of solar energy which is 3000 times higher than the electricity generated as of year 2006 in the country [48]. Average monthly solar irradiation in six divisional districts is presented in Fig. 12 [73]. It is found that 94% of the land area in Bangladesh have such radiation which is sufficient for appropriate utilization based on available technology [48].

Maximum radiation begins from March to April, and minimum – December to January [74]. The highest solar radiation is found at Rajshahi district showing an immense potential of solar energy utilization [75].

Table 7
Solar PV installed capacity in selected Asian economies (in MW) [2].

Country	2006	2007	2008	2009	2010	2011
China	80	100	140	300	800	3000
India	30	31	71	101	161	427
South Korea	36	81	358	524	656	748
Malaysia	6	7	9	11	13	13

4.2.1. Concentrating solar power (CSP) technology

Solar energy harnessing technology, for instance, concentrating solar power (CSP) could generate estimated 100 MW of electricity when annual average direct normal insolation (DNI) is about 2000 kWh/m^2 for an given area of 2 km^2 [72]. The average annual DNI that Bangladesh receives is about 1900 kWh/m^2 which is found sufficient in Rajshahi district to utilize such technology [76]. Even though, if such technology might have lagged to generate expected outcome, CSP–battery hybrid system can be introduced to meet such short deficit. Among the major CSP technologies developed such as, parabolic trough, parabolic dish, solar tower and Linear Fresnel Reflector (LFR); parabolic trough and parabolic dish are found theoretically suitable for Bangladesh environment [72], however substantial investment from GOB and other developing partners are required to harness full potential of such solar energy technology in Bangladesh. Besides this high capital intensive technology which is relatively at research and development stage, some of the technologies found vividly successful in Bangladesh, such as SHS, solar PV, and solar cooker. There are about 61,500 solar PV systems and 260 hot box cookers have been installed in the rural, coastal and hill tracks area in Bangladesh by different non-government organizations (NGOs) and government institutions [73]. At present, total installed capacity of solar PV systems is 3 MW [73] and this number is increasing day by day. According to research conducted by 'Promotion of Renewable Energy, Energy Efficiency and Greenhouse Gas Abatement (PREGA)' revealed that if 10% efficiency is considered for solar cell, estimated electricity generation from solar PV will be 50,436 MW in Bangladesh, as of 2003 [77].

4.2.2. Grid-connected solar PV system

The concept of grid-connected solar PV power system opened up new dimension of renewable energy utilization technique. It has the advantage of more effective and efficient utilization of generated power from PV array and main distribution line. Fig. 13 shows the arrangement of grid-connected solar PV power system with no storage [78]. Grid-connected PV system can be used in an

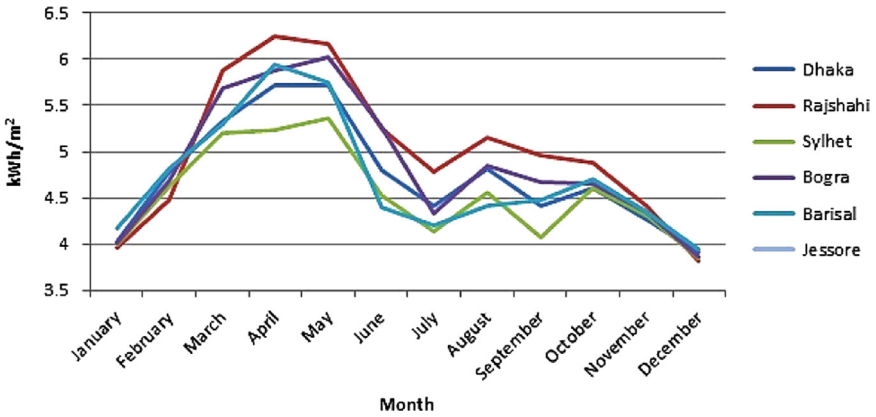

Fig. 12. Average monthly solar irradiation in Bangladesh [73].

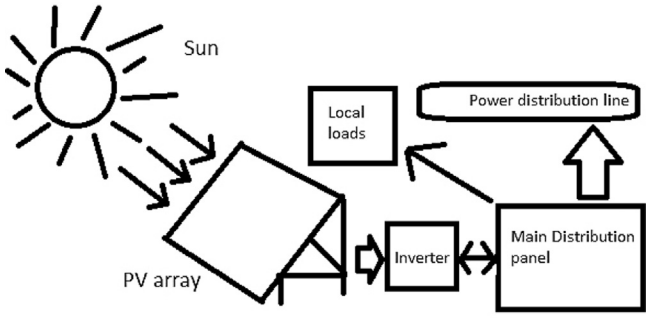

Fig. 13. Grid-connected PV power system with no storage [78].

integrated building system and native PV system. From the last decade, the application of grid connected PV solar system was first initiated in US (California), Japan, Germany; and as of 2005, the total installed capacity of grid-connected PV system reached 300 MW in Japan, and 70 MW in the USA with an annual increase of 75% considering all the countries [79]. It was expected that grid-connected solar PV rooftop program in the above mentioned countries could reach 650,000 MW of electricity because of supporting policies [78].

In Bangladesh, only 48.5% of the total population have grid connected electricity supply [80]. Bangladesh is at the nascent stage of implementing such kind of renewable energy harnessing technique. There is no commercial scale solar energy industry in Bangladesh and moreover, there is no coordinating authority for renewable energy sector in Bangladesh [73]. It was estimated that technical potential of grid-connected PV system in Bangladesh is around 50,174 MW [81]. Depending on the location of 14 districts of the country, it was calculated that annual electricity generation varies from 1653 megawatt hour to 1854 megawatt hour (MWh), with an average of 1729 MWh [81]. It is estimated that 500 kW grid connected solar PV system can reduce 658 tons of greenhouse gas [82]. Dhaka, capital of Bangladesh is the highest densely populated megacity in the world with more than 14 million population [83]. Energy crisis has become an important issue, particularly in the urban areas. Existing roof tops present in the Dhaka city can produce 1000 MW of electricity generation, estimated by an individual 75 watt power (Wp) PV system setup [83]. Currently, Dhaka city is facing tremendous challenge to meet 1000–1200 MW power shortage against 2000 MW peak demand [83]. Adequate policy should be taken to promote roof-top solar PV and grid connected solar PV system in the urban areas mitigating future electricity demand. In rural Bangladesh, health care system is not well organized and power crisis in the hospitals is a usual phenomenon which is considered as a barrier utilizing modern health care services. Solar PV system can play an important role to mitigating such power crisis. Some of international NGOs, for instance, Bangladesh Rural Advancement Committee (BRAC) installed solar PV system in their rural branch offices, health clinics and training centers [57]. According to the authors in [84], grid-connected solar PV system needs substantial strategic refinement in future addressing

> "*With respect to the future, the most important perception is, with looming grid parity, a major challenge will be to link incentives for the effective own use of PV with market-based prices for feeding PV electricity into the grid. This investigation is left for future research work.*"

As grid-connected solar PV system study is relatively new in Bangladesh, collaborative research partnership with the institute or organization from successful country can make positive and directional research outcome in the Bangladesh context. Smart grid – proposed by Chowdhury et al. [80] could be a cost effective and highly reliable hybrid energy system for rural and areas in Bangladesh. Moreover, minimizing cost and reduction in size and weight are required for more utilization of grid-connected solar PV system. Green entrepreneurship can be developed which will create new opportunity by manufacturing low cost PV array panel and other important components, such as inverter.

4.2.3. Solar home system (SHS)

SHS achieved remarkable success as off-grid power generation at rural and remote areas for domestic and small businesses [85]. The installed capacity of SHS is increasing at promising pace. As of February 2012, numerous government and non-government organizations installed 1,320,965 SHSs [86], with installed capacity of 36.5 MW electricity [25]. Among the organizations, Grameen Shakti (GS) installed 750,657 which is the highest [86]. Table 8 shows summary of SHS installation up to April, 2012 in Bangladesh by partner organizations [86]. It is estimated that by 2015, number of decentralized solar unit, such as SHS will reach 2.5 million [20]. Fig. 14 shows total number of SHS installed in Bangladesh [87]. According to recent regulation, high rise building in Dhaka city must install solar PV system to attain grid connected electricity [77]. The highest and lowest numbers of SHSs have been installed in Dhaka and Sylhet division which are 374,587 and 151,914, respectively [87]. Bangladesh government has taken holistic approach to promote and install SHS, and it is assumed that generation capacity will reach 50 MW [3] installing 4,000,000 SHS around the country by 2015 [77].

In the absence of adequate power supply, rural life style was less productive in terms of income generation and extended working hour. SHS showed promising contribution not only in electricity generation but also creating jobs and alleviate poverty. However, SHS should not be considered as comprehensive alternative poverty

Table 8
Summary of SHS installation up to April, 2012 in Bangladesh [87].

Partner organization	Number of SHSs installed
Grameen Shakti	795,957
RSF	216,434
BRAC	77,019
Srizony Bangladesh	58,927
Hilful Fuzul Samaj Kallyan Sangstha	37,078
UBOMUS	25,234
BRIDGE	20,449
Integrated Development Foundation	14,238
TMSS	13,059
PDBF	10,672
SEF	21,720
AVA	12,817
DESHA	10,931
BGEF	16,995
RDF	20027
COAST	6181
INGEN	9871
CMES	5714
NUSRA	9372
RIMSO	8196
Shubashati	5370
REDI	5711
GHEL	6138
SFDW	9485
PMUK	2166
Patakuri	3409
ADAMS	2848
AFAUS	1161
RISDA	1552
Xenergeia	320
Other	389
Total	**1,429,440**

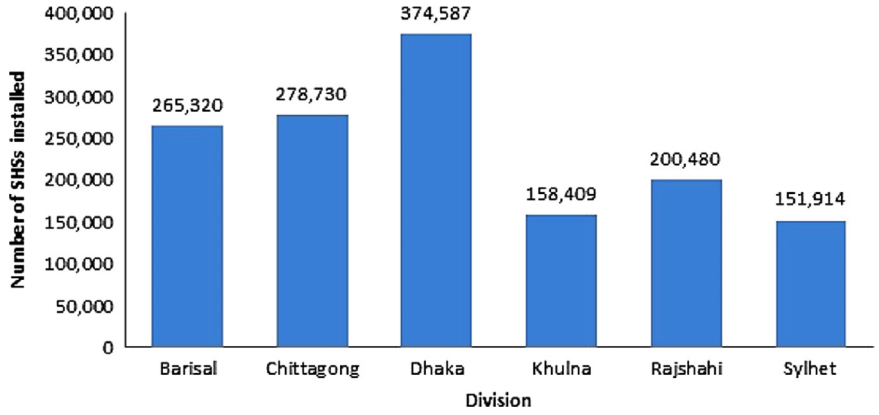

Fig. 14. Number of SHSs installed in Bangladesh (division wise) [87].

Table 9
Potential power generation from selected solar energy technology.

Solar energy utilization technology	Potential power generation (in MW)	Source
CSP	100	[72]
Grid connected solar PV	50,174	[81]
SHS	50	[3]

reduction tool for a country like Bangladesh, but it attributes to noticeable social benefit and change in livelihood in rural Bangladesh [81]. Green entrepreneurship as well as employment in the renewable energy sector can be developed through marketing and promotion. As of December 2011,1.2 million SHS have been installed that created estimated 60,000 jobs in the green energy sector [20].

Solar energy has a numerous potential which can be tapped with appropriate technology in the context of Bangladesh [51]. Table 9 shows potential power generation from different solar energy technology. Grid-connected solar PV has the highest potential in utilizing solar energy. However, as a decentralized system, SHS is a promising technology that can extend in rural Bangladesh proving subsidies and large scale investment from government and non-government organization. Furthermore, research conducted by Nandi and Ghosh [88] showed that a wind–PV–battery hybrid system can produce approximately 89,151 kWh/year in which 53% of electricity is coming from wind and solar energy, which is considered as a promising technological innovation for decentralized electricity generation in remote areas [88]. Besides, electricity generation, solar energy can be used as solar air heater for space heating [89]. Similar and further modified setup should be utilized drying rice and other agricultural products in the context of Bangladesh. For cooking purpose, solar cooking system has distinct advantages over conventional concentrators and box cookers, when evacuated tube collectors have been implemented in design [15]. Grameen Phone (GP), the largest mobile phone operator in Bangladesh, installed two PV–diesel hybrid systems with 8.05 kWp each, for power supply to their off grid Base Transceiver Station (BTS) in Hobigang district while planning to install 12 more hybrid systems across the country [43]. However, it is a fact that no ground measurement data exist for Bangladesh [90]. To achieve 10% renewable energy mix by the year 2020 [91], GoB and other developing partners should clearly take action against this technological deficit.

4.3. Wind energy

Wind energy is one of the fastest growing renewable energy sector of present time [92]. Wind turbine is used to convert wind energy to electricity, pumping water and so forth. Production and consumption of wind generated electricity was nearly zero in the early 1980s. Consumption of electricity from wind energy has reached 437.4 TWh in 2011 [2]. Globally, wind turbine installed capacity was 6.1 GW in 1996 that reached 238 GW in 2011. Wind turbine installed capacity was increased 40 GW only in year 2011. Wind energy currently accounts for 38.1% of total electricity generation in Germany. On the other hand, the US and China represents world's wind power installed capacity of 61.1 GW. Fig. 15 shows a progressive increase in wind turbine installation of top five countries [20]. Asia became the top investor in renewable energy field, especially in wind turbine sector; among those China and India are at the top. The total installed capacity of wind turbine in China and India stood 62.421 GW and 16.078 GW, respectively in 2011 [2].

Table 10
Annual average wind speed of different sites in Bangladesh [50].

Site	Reference height (m)	Wind speed (m/s)
Teknaf	5	2.16
Cox's Bazar	10	2.42
Potenga Airport	5	2.45
Kutubdia Island	6	2.09
Sandip Island	5	2.16
Hatia Island	6	2.08
Bhola Island	7	2.44
Khepupara Island	10	2.36
Comilla Airport	6	2.21

Wind energy potential is not encouraging except in some coastal areas of Bangladesh [11]. Bangladesh has a costal belt of around 724 km along the Bay of Bengal consists of several islands. However, commercial power generation from wind turbine requires adequate techno-economic evaluation [48], which is not readily available. On the other hand, a well-constructed wind map and ground data is essential for assessment harnessing wind energy potential [93]. Geographically, strong south–south-east monsoon wind comes from Indian Ocean enters into the coastal area of Bangladesh after a long distance traveling through Asia. Approximately, from March to September wind blows at an average speed of 3–6 m/s over Bangladesh [94]. Study conducted by the Bangladesh Meteorological Department (BMD) found average wind speed during study period of 1991–1993 listed in Table 10 [73].

Global wind data and research shows that wind speed not more than 7 m/s is not viable for large scale grid connected electricity production within wind parks [73]. In most cases, measured values of wind speed are not present in Bangladesh. Up to present, several study conducted by Bangladesh Center for Advance Studies (BCAS), BMD and Local Government Engineering

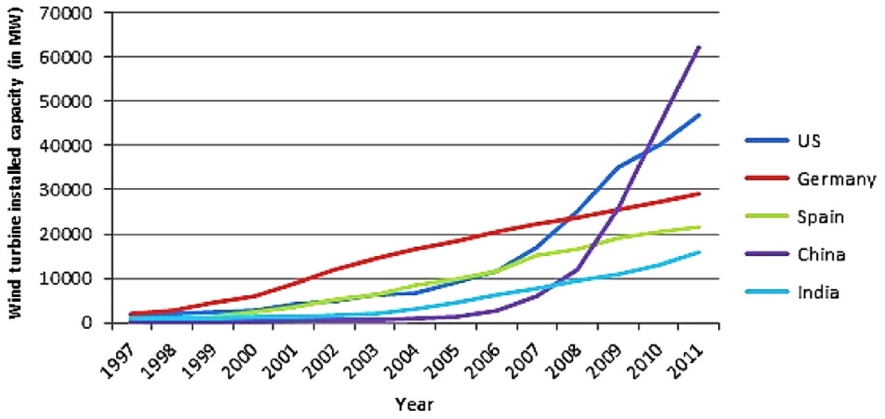

Fig. 15. Installed capacity of wind turbines in selected economies (in MW) [2].

Department (LGED) revealed that wind speed varies from 2.96 to 4.54 m/s at a height of 25 m and 50 m in different parts of the country [73]. From literature, it is found that total wind turbine installed capacity in Bangladesh, varies from 20 kW to 50 kW [11,95]. Besides, LGED is actively engaged in manufacturing low cost pumps. Prototype based pumps can lift 20,000 l of water per day by average wind speed of 4 m/s. In total 6 prototypes have been installed in the country [11]. Global wind energy is growing at an expanding rate due to eco-friendliness and bulk power generation capabilities. Bangladesh is on its footstep to harness wind energy potential. At present, wind mapping and necessary ground data should be acquired to assess the full potential of wind energy. Considering a vast segment of population who are out of on-grid electricity, wind energy can substantially provide off-grid power in remote areas [96]. Affordable and reliable solar photovoltaic technology as well a durable and economic battery production would be an effective strategy for disseminating renewable energy in the rural electrification [97]. More research and development in the area should be conducted with comprehensive analysis, based on geographical context of Bangladesh.

4.4. Small scale hydro power energy

Worldwide, small-scale hydropower became popular because of low cost, reliability and environmental benefits. Globally, renewable energy contributed 208 GW of electricity as of 2011, where hydropower accounts for 25% of the total energy production [20]. Due to geographical flatness, Bangladesh has limited hydropower potential [40]. However, research findings show that in the existing geographical location, approximate hydro power potential is about 500 MW out of which, small scale hydropower plants have potential to generate electricity of 5 MW [46]. Potential sites for hydropower have been discovered at Chittagong Hill Tracks (CHTs) area, and river basin of Matamuhuri and Sangu. Exploration and feasibility studies have been carrying out since 1981 by Bangladesh Water Development Board (BWDB) and Bangladesh Power Development Board (BPDB) of GOB. Definition of small scale hydropower varies depending on available heads and generation capacity. Micro-hydro power can generate 5–300 kW of electricity [25]. A list of potential sites of small scale hydropower found from the studies is summarized in Table 11 [98]. In 2008, LGED reported several potential sites for micro-hydro power plant with a power generating potential up to 30 MW (Fig. 16) [99].

Moreover, sustainable rural energy (SRE) has identified potential sites in the CHT areas in 2004 for micro-hydro power plants. Among the micro-hydro sites, Bemerchara showed prospect of electricity generation capacity of 4 kW [44]. More feasibility study should be carried out to harness full potential of small scale hydro energy in Bangladesh. Most of the small scale hydro power potential sites were discovered in rural, remote and hill tracks areas of the country which can contribute to overall socio-economic development of the country ensuring power supply for the rural population.

Table 11
Potential small hydro sites identified by BWDB and BPDB [57].

District	Name of river/chara/stream	Potential energy (kW)
Chittagong	Fiaz lake	4
	Chota Kumira	15
	Hinguli Chara	12
	Sealock	81
	Lungi Chara	10
	Budia Chara	10
Sylhet	Nikharai Chara	26
	Madhb Chara 1500-ft from fall	78
	Ranga pani Gung	616
Jamalpur	Bhugai-Kongsa	65.5
	Marisi	32.5
Dinajpur	Dahuk	24
	Chawai	32
	Talam	24
	Pathraj	32
	Tangon	48
	Punarbhaba	11
Rangpur	Chikli	32
	Fulkumar	48

5. Conclusion

Energy sector of Bangladesh heavily relies on conventional primary energy sources such as natural gas, coal and imported crude and refined petroleum products. Natural gas is the predominant energy source that the country is currently utilizing to its maximum. Coal and limited hydropower energy also shares limited percentage in the total power generation. Economic growth and continual prospect in socio-economic development fundamentally relates to efficient and effective dissemination of, not only primary conventional energy sources but also alternative energy, as the formers are depleting. Only 20–30% of the total population is currently under electric supply [100]. Energy demand will increase 185% by year 2020, and to plan such escalating phenomenon, GOB envisioned planning renewable energy share increase to 10% by that time which requires substantial allocation of resources, large investment and appropriate policy implication. Depleting energy sources contribute

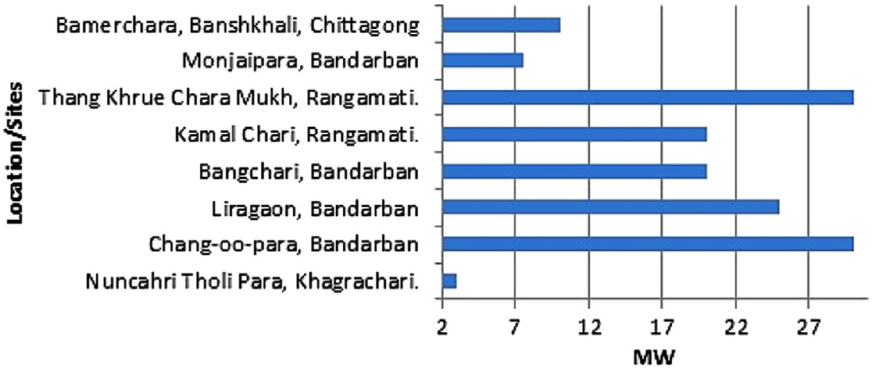

Fig. 16. Potential power generation from micro-hydro in Chittagong district [99].

to greenhouse gas emission, resulting adverse climate change, by which, Bangladesh is already in vulnerable condition.

Dissemination of renewable energy in the mainstream energy supply may not be readily available to Bangladesh all of a sudden; however, GOB has taken rigorous initiatives implementing various policies and programs towards achieving target of per capita electricity consumption 600 kWh by 2020 [101]. Public awareness in rural areas of the country regarding renewable energy utilization showed positive direction in recent times, especially in SHS technology. SHS showed promising impact in job creation and local entrepreneurship development. As an Argo based economy, Bangladesh has the highest potential utilizing biomass energy source within sustainable energy system. More than 70% of the population resides in the rural areas [51] where biomass could be the top contributor to sustainable energy source if it is appropriately harnessed considering contextual identification of technology, culture and mass awareness.

Government, non-government organizations, and international donor agencies have the role to play in wider utilization of renewable energy in Bangladesh. To secure future national energy security, and aiming to provide constant and quality power supply to all citizens of Bangladesh, GOB must strive to double its effort towards attaining greater renewable energy share by conversion, utilization and dissemination in coming years.

Acknowledgment

The first author like to thank Mr. Mehedi Bin Mohammad, Ph.D. student, Swinburne University of Technology, Melbourne, Australia for his useful suggestion on CSP technology. We also thank the anonymous reviewers for their valuable and constructive comments which was one of the strong contribution.

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